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# Investigation of Hardmask/BARC Materials for 157nm Lithography

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## ABSTRACT

157nm lithography is expected to be the lithography choice for the 100nm-technology node, which is scheduled to be in full-production in 2003. However, due to 157nm photons being strongly absorbed by commonly used polymeric organic materials, a completely new class of material (containing F and Si-O) will be needed for 157nm Single Layer Resist (SLR) system. It is expected that the 157nm SLR system development will take greater than 3 years, which the industry will barely have, until the projected 2003 production schedule. In an attempt to fill the gap and to provide working resist system, using thin (<100nm) films of existing resist materials along with inorganic thin hardmask/BARC films is an attractive approach.

In this paper, we report the optical constants ( $n$  &  $k$  at 157nm as well as 193nm and 248nm) of various thin film hardmask/BARC candidate materials ( $\text{Si}_x\text{N}_y\text{H}_z$ ,  $\text{Si}_x\text{O}_y\text{N}_z$ ,  $\text{Si}_x\text{C}_y$  CVD and  $\text{Ti}_x\text{N}_y$  PVD films) measured by VUV-VASE. The films' atomic compositions, determined by RBS/HFS, were varied by controlling feed gas flow rates in order to vary the optical behavior. However, we limited our study within the low process temperature PE-CVD and PVD films due to our intention of using these films along with LowK (2.7~2.0) dielectric materials. In addition, we will also report the optical constants of two types of LowK materials (PE-CVD OSG film and Spin-On/Cure low-density organosilicate dielectrics by JSR).

The data is, then, used to optimize the physical properties ( $n$  &  $k$ ) and utilized to determine suitable hardmask/BARC material for 157nm exposure using Prolith II simulation. The results containing property of these hardmask/BARC candidate films and our optimization analysis along with the first successful pattern transfer feasibility demonstration into realistic substrate material (poly-Si) using ultra thin resist (currently existing) at 157nm optical lithography are reported.

**KEYWORD:** 157nm, hardmask, BARC (Bottom Anti Reflective Coating), optical constants,  $n$  (index of refraction),  $k$  (extinction coefficient), VASE (Variable Angle Spectroscopic Ellipsometry), VUV-VASE (Vacuum Ultra Violet-Variable Angle Spectroscopic Ellipsometry), RBS (Rutherford Backscattering Spectrometry), HFS (Hydrogen Forward Scattering).

## 1. INTRODUCTION

Ever accelerating ITRS roadmap [1] requires 157nm lithography, using  $\text{F}_2$  laser, be ready for 2003 early-production. To meet this tight schedule, much work is being carried out by researchers around the world. As part of these efforts, International Sematech (ISMT) has acquired small field (1.5X1.5mm) microstepper to facilitate much needed photoresist material development. However, due to traditional organic photoresist materials (successfully used at 248nm and 193nm lithography) having strong absorption at this wavelength, development of single layer photoresist system design to work at this wavelength will require substantial amount (at least several years) of intensive research efforts. Traditional single layer resists (SLR) schemes are still the preferred choice for device manufactures, however it is not very certain that SLR system will be ready in time for 2003 production using 157nm lithography. Because of the strong absorption of existing resist material, employing existing material will require use of Thin Layer Imaging (TLI) technique. One of the TLI technique under consideration is using Ultra Thin Resist (UTR) over inorganic hardmask [2] which offers advantages in both thinner resist required for sufficient resist pattern fidelity and the etch resistance requirements in subsequent pattern transfer process.

Depending on the absorption level of the photoresist formulation the thickness of resist layer is expected to be less than 100nm. Using photoresist designed for 248nm exposure will limit the resist thickness <80nm.

To design optimum stack (imaging resist layer, etch resistant hardmask layer over substrate to be patterned), to allow best lithographic performance, requires knowledge of optical constants ( $n$  &  $k$ ) of these materials considered at the intended exposure wavelength (157.6nm). Due to strong absorption of 157nm light by molecules abundant in ambient lithography environment ( $O_2$ ,  $H_2O$ ,  $CO_2$  . . . etc.) very limited number of metrology tools operating at this wavelength has been available. Variable Angle Spectroscopic Ellipsometry (VASE) offers accurate and fast measurements of optical constants of thin films. The VUV-VASE tool ISMT acquired has capability of measure optical constants from 142nm to 1100nm.

In this paper, we report the optical constants (at 157.6nm as well as 193nm and 248nm) of various low process temperature CVD and PVD film hardmask/BARC candidate materials (Silicon Nitride, Silicon Oxynitride, Silicon Carbide and Titanium Nitride films) measured by VUV-VASE. The films' atomic compositions, determined by RBS/HFS, were varied by controlling feed gas flow rates in order to vary the optical behavior. We also report the optical constants of two types of LowK (2.7~2.0) dielectric materials (PE-CVD OSG film and Spin-On/Cure low-density organosilicate dielectrics by JSR) and a bi-layer resist system. The data were, then utilized to determine suitable hardmask/BARC material for 157nm exposure using Prolith II simulations. The results containing property of these hardmask/BARC candidate films and our analysis are reported. Finally, "proof-of-concept" patterning demonstration using early 157nm exposure of TLI-UTR technique, using, ordinary-organic, existing resist material, is presented.

## 2. EXPERIMENTAL

Optical constants (refractive indexes,  $n$  and extinction coefficients,  $k$ ) determined in this study were from the VASE measurements taken on a Woollam VUV-VASE (VU-301) ellipsometer. The system is based on the DUV-VASE (190-1700nm) system, however with vertical sample stage that is completely encapsulated in nitrogen purged chamber. Due to strong absorption of VUV light by ambient oxygen and water vapor, entire system is purged with dry nitrogen gas. D2 sources, in addition to Xe source, and PMT detector, in addition to Photodiode detector, have been added to increase short wavelength capabilities as well as boost in S/N ratio in the DUV range. The system is also equipped with auto retarder, which allows the ellipsometer to distinguish un-polarized light; and double-chamber monochromator (HS-190), which features superior stray-light rejection capability. Typical measurement consists of set of data measured at three angles ( $60^\circ$ ,  $67.5^\circ$  and  $70^\circ$ ) which was then used "fit" to determine the optical constants. All data were acquired and analyzed using WVASE32 version 3.255b.

Films studies in this work were generated as shown below. Standard silane chamber with giant process kit and p-chuck susceptor on an Applied P5000 dielectric CVD tool was used to deposit various SiN, SiON and SiO<sub>2</sub> films. A Novellus dielectric CVD tool was used to deposit SiC, SiN and OSG films. A Varian M2000 PVD tool employing poisoned TiN process was used to deposit TiN film. A SVG vertical furnace was used to deposit Low Pressure (LP) CVD TEOS (LPTEOS) film. Coated and cured SOD wafers were provided by JSR. A FSI Polaris 2000 clean track system was used to coat/bake bi-layer resist materials. Film compositions as atomic compositions in SiN, SiC and TiN films were determined by Rutherford Back Scattering (RBS) and Hydrogen Forward Scattering (HFS) spectroscopic analysis carried out by Charles Evans & Associates.

Lithographic experiments were performed at the Resist Test Center (RTC) in the ISMT cleanroom. The resist used in this study (2D)<sup>a</sup> was spin-coated followed by softbake (PAB, 145°C/60sec). F<sub>2</sub> (157.6nm) exposures were carried out on a 10X reduction 0.6NA Exitech small-field (1.5X1.5mm) microstepper with conventional (0.7 $\sigma$ ) illumination using a simple binary mask, followed by post exposure bake (PEB, 145°C/60sec) and developed (0.26N TMAH for 40sec). Wafer coating, PAB, PEB, develop processes are all integrated on a FSI Polaris 2000 clean track system. A Lambda Physik laser (F630) provides 157.6nm radiation source. Cauchy coefficients were used to determine film thickness using a Prometrix SM300 reflectometer. Chemical filters are installed on our exposure and coat/develop tools, and both inside of those tools, FAB ambient air and outside air are monitored for amine concentrations using IMS amine analyzer and Extraction System Total amine monitor. Less than 1ppb amine concentrations were always measured on those chemically filtered Exitech

<sup>a</sup> 2D: XP98248-S; EUV version of UV6 from Shipley.

microstepper and FSI coat/develop cluster; and between 3 and 5 ppb were measured in the FAB ambient and outside air. Since, the exposure tool and coater/developer tool are not interfaced and physically separated (~15ft.), we made sure to transfer wafers between these tools as quickly as possible to avoid possible amine contamination. With planning and practice, we were able to transfer wafers back and forth within ~10 seconds exposure to the FAB ambient air. Lithography simulations were carried out using Prolith/3D (ver6.1.0.1) simulator running on a PC.

Hardmask etch was carried out on a TEL Unity II DRM chamber and poly etch was done on Lam TCP 9400PTX chamber. No end-point detection method was used. Simple time based etch time was employed based on daily etch rate qualification tests of the blanket wafer etch rates. Resist removal process utilized Fusion ash chamber. Hardmask was removed using BOE (Buffered Oxide Etch) wet process.

### 3. RESULTS AND DISCUSSION

#### A. Optical Constants (n & k)

In this study, we investigated various inorganic and organic materials as hardmask/BARC candidates for 157nm lithography.

All the optical constants (n & k) measured in this study are gathered in *Table I*. In this table, we include n & k values at 193nm (ArF) and 248nm (KrF), two other lithographically important wavelengths, in addition to at 157.6nm (F<sub>2</sub>), for comparison purpose. We also found that, especially at 193nm, quality of measured data are much superior to the measurements using DUV-VASE (down to 190nm in ambient surroundings) instrument, leading to much accurate and confident determination of optical constants at this wavelength. *Table II* shows various SiN film depositing conditions (DOE 1-3, where DOE2 represents our standard, baseline, condition) and corresponding atomic composition determined by RBS-HFS analysis and optical constants determined by VUV-VASE measurements. A plot of %Si vs. either the constants show linear relations as shown in *Figure 1*. In fact, inclusion of literature value [3] of crystalline silicon (100% Si) yet show very linear correlation.

In *Figure 2*, n & k of SiO<sub>2</sub> (LPTEOS), SiON and SiN are compared. In this plot, we can readily note that index of refraction of SiON lies in between SiO<sub>2</sub> and SiN. However, in case of extinction coefficient, SiON absorbs more than SiN above ~180nm. This property of SiON has been utilized as popular BARC material for 193nm and 248nm lithography.

Plot of optical constants of PE (Plasma Enhanced: single wafer process using plasma chamber) and LP (Low Pressure: batch process in vertical furnace) CVD-TEOS oxide are shown in *Figure 3*. While index of refraction of both films are quite similar, it is interesting to note that PE-CVD film has absorption peak at shorter wavelength (167nm) than for LP-CVD (196nm) film. We speculate this observation is due to inclusion of organic species in PE-CVD process; effect of rapid (>100A/sec) deposition process in plasma chamber.

A similar *Table III* shows various "silicon carbide" (SiC) film deposit conditions (DOE1-8, where DOE3 represents our standard condition) versus corresponding atomic compositions and optical constants. The DOE1-6 varied by +/- 10% the most significant process variable with the most impact on the film properties, including refractive index and FTIR peak heights. DOE1-2 varied the most significant process variable by -10%, DOE3-4 represents the center point, and DOE5-6 varied the most significant process variable by +10%. The numbers in parenthesis are the film thickness in angstroms. Both RBS-HFS data and VUV-VASE data indicate that these films are not much different in terms of atomic compositions and optical constants. Within these conditions, it appears, these processes generate films with very stable physical and optical properties. Consequently, optical properties tuning, intentions of lithography performance improvements would require additional process developments. DOE7 and DOE8 were carried out to determine differences between a "series" (6-shower stations) of deposition processes and a "single" deposition process for the same final film thickness. Again, we found very little differences in physical and optical properties.

Comparing optical constants of two different thickness films (i.e. ~250A and 500A), we found significant variations in their optical properties as illustrated in *Figure 4*. We believe these differences are due to significant physical property non-uniformity (vertical index grading) within the film. This phenomenon is understandable that since these PE-CVD films are produced using very rapid deposit process; in soup of chemical plasma, where very short period of time (<10 seconds) is

needed. Thus, we feel that optical constants of this type of films are "apparent" values only and recommend one to determine the apparent value specific to his/her own process at exact thickness. We also believe that this type of film (contains at least 5 different atomic components) is particularly complex in their compositions.

*Table IV* shows various "titanium nitride" (TiN) film deposit conditions (DOE1-5, where DOE1 represents our standard conditions) versus corresponding atomic compositions and optical constants. In an attempt of varying Ti and N composition, we have varied N<sub>2</sub> (2 level 39 and 78 sccm) and Ar (3 level 0, 10.5 and 21 sccm) flows. As indicated by *Figure 5*, while N<sub>2</sub> flow has strong impact on Ti and N composition ratio Ar flow has no impact on Ti/N ratio. However, optical constants measured at various wavelengths indicated that inclusion of Ar gas definitely effects the optical constants especially at short wavelength regions (i.e. DOE1 vs. 2 at 157nm). We believe this is due to morphology changes nature of TiN film due to added Ar gas, however exact contribution of its role still need to be determined. Thus, again, we recommend ones to determine the optical constants of their own specific film at specific process conditions, better yet at specific thickness, for use as hardmask/BARC layer. We also noted that our findings do not agree with values available on the web [4] from R.I.T., upon comparison of our measured optical constants to the published numbers. We again believe, optical constants of TiN depend on many factors and can vary widely depending on process conditions.

Plots of TiN n and k values are shown in *Figure 6*. One distinctive feature of this plot is the high extinction coefficient exhibited by this material, especially at longer wavelengths, and corresponding low index of refraction. These properties have been utilized as a mainstream BARC materials at the longer wavelengths' (i-line, g-line and 248nm) optical lithography and thus much of know-how exists for processing of this material (depositing, etching, striping... etc.) in semiconductor manufacturing process.

Finally, plot of n and k of LowK (dielectric constant) films (OSG: Organo Silicate Glass and SOD: Spin-On Dielectric) determined in this study are shown in *Figure 7*. The OSG (K~2.7) film is the prime candidate for IMD (Inter Metal Dielectric) and ILD (Inter Layer Dielectric) for Dual-Damascene (DD) interconnect structures in 130nm devices generation, while SOD (K~2.3) is targeted as candidate for 100nm device generation. Since, several tight pitch (i.e. Metal 1 to 3 or 4 called "signal leads") lithography for 130nm generation process will require ArF (193nm) exposures (and, similarly F<sub>2</sub>, 157nm, exposure for 100nm node), knowledge of optical constants of these materials at these wavelengths are critical.

## B. Using the Constants.

Due to strong absorption of F<sub>2</sub> laser light in films of ordinary-organic resists, resist thickness must be very thin (<100nm) when existing (designed for 248 or 193nm exposure) resists are used for 157nm exposure. However, using such a thin resist layer presents problem that it will not provide much etch resistance upon subsequent substrate etch process. Si-containing bi-layer system [5-8] can be employed. However, using top (Si containing imaging layer) layer below 100nm has never been tested. *Figure 8* shows poly lines (100nm, 1:1.5) patterned (A: bottom layer dry-developed, B: post poly etch, C: bottom resist ashed off) using ultra thin bi-layer processes<sup>b</sup>. In this experiment, small geometry (100nm) on the imaging layer was patterned using alternating PSM mask at 193nm exposure<sup>c</sup>. Both dry develop<sup>d</sup> and poly etch<sup>e</sup> were carried out using Lam 9400PTX chamber. The bottom layer resist was stripped<sup>f</sup> using a Fusion ash chamber.

Resist reflectivity (*Figure 9*) was calculated to determine optimum top/bottom bi-layer thickness for contact hole patterning on 600nm of PETEOS film. The results indicated that 80nm of top resist on 230nm of bottom layer resist is an optimum choice (star) for 193nm exposure for this system. The simulation also indicated that 157nm exposure could be also carried out at the same chosen top/bottom thickness combination although it is not at perfect optimum.

SEM micrographs shown in *Figure 10* are a collection of dielectric film (PETEOS and OSG) etching demonstrations using ultra thin bi-layer process, where tilt (A,B,E,F) and cross section (C,D,G,H) view of dry developed (A,E,C,G) and dielectrics

<sup>b</sup> 80nm of top layer and 220nm of bottom layer

<sup>c</sup> as part of preliminary studies; prior to 157nm-exposure capability at ISMT

<sup>d</sup> Step1: Main Etch; 15mT, T/B=500/75W, O<sub>2</sub>/SO<sub>2</sub>=20/30sccm, 40sec, Step2: Over Etch; 15mT, T/B=500/75W, O<sub>2</sub>/SO<sub>2</sub>=10/40sccm, 20sec; all @ -10°C

<sup>e</sup> Step1: Break Through; 10mT, T/B=100/200W, Cl<sub>2</sub>/HBr=50/50sccm, 10sec, Step2: Main Etch; 20mT, T/B=450/45W, Cl<sub>2</sub>/HBr/He/O<sub>2</sub>=75/200/5/5sccm, 60sec; all @ 60°C

<sup>f</sup> 1Torr, 1500W, O<sub>2</sub>/N<sub>2</sub>+H<sub>2</sub>/CF<sub>4</sub>=2000/300/5sccm, 60sec @ 270°C

etched (B,D,F,H). PETEOS (A,B,C,D) and OSG (E,F,G,H) pictures are gathered. Lithography for this demonstration was carried out at 193nm (0.6NA, 0.7 $\sigma$ ), again prior to 157nm exposure capability at ISMT, and dry development and dielectric etch was carried out using TEL DRM chamber employing TEL proprietary processes<sup>g</sup>.

*Figure 11* shows Prolith II simulation results and their corresponding experimental cross section micrographs of resist sidewall profiles for resist (2D) thickness of 65nm (A), 70nm (B) and 75nm (C) indicating accuracy and usefulness of our measured optical constants reported in this study<sup>h</sup>. Based on this result, we implemented this process<sup>i</sup> as our baseline process in our early effort of characterizing Exitech F<sub>2</sub> microstepper lens. This resist, however, is highly absorbing (k=0.196 or B=15.68) upon 157nm light, thus limits its use at very thin thickness (<80nm). To use this resist in subsequent etch process we need hardmask material that can withstand harsh substrate etch process condition. Choice of hardmask material and its optimization is considered below.

For highly absorbing resist material (2D at 157.6nm) we envisioned that certain amount of reflected light will be necessary to achieve straight sidewall profile which requires fairly transparent material as hardmask choice. We chose to use oxide film as our hardmask for etching 100nm of poly lines. Our attempt of using more common BARC candidate materials (SiON, SiN. . . etc.) did not yield satisfactory sidewall profiles due to too high absorption of resist and BARC always result in heavily sloped sidewalls (both simulations and experiments). However, this trend (requirement of transparent hardmask) should reverse when more transparent resist material is available for 157nm lithography just as at longer wavelengths (193, 248 and 365nm).

Usual practice in picking optimum BARC and resist thickness is; first to determine BARC thickness to minimize substrate reflectivity, and then resist thickness that offers least resist reflectivity – also considering subsequent etch selectivity of the films involved. *Figure 12* shows such analysis (Prolith II simulations) for patterning 100nm of poly lines using LPTEOS hardmask and 2D resist at 157nm exposure. However, our initial 157nm exposure experiments (we observed unacceptable LER) as well as resist profile simulation (*Figure 13*) indicated that for highly absorbing resist (i.e. 2D at 157nm), this method of picking BARC/resist thickness does not always yield best outcome. Therefore, we conducted exhaustive resist profile optimization simulations, emphasizing the resist sidewall profile as primary criterion, as shown in *Figure 13*. As can be easily seen in *Figure 14*, optimum BARC/resist combination for 2D resist on LPTEOS was turned out that picking optimum thickness is not as simple as of picking minimum substrate and resist reflectivity (round dot) but one must pick the thickness combination that yields best resist profile (star). It is interesting to note that certain amount of substrate reflection is needed to achieve best sidewall profile for 2D exposing at 157nm, and the thickness combination chosen this way does not seem to have any relationship to simple reflectivity optimization model. We chose to use 2D/LPTEOS thickness of 67/42nm predicted by this analysis instead of 65/52nm predicted by reflectivity model as illustrated in *Figure 15*.

Experimental, lithography and etch, results using 67nm of 2D resist<sup>j</sup> and LPTEOS as hardmask material are shown in *Figure 16*. 130nm (1:1.5) resist pattern (A) was defined lithographically at 157.6nm<sup>k</sup> which was then transferred into the hardmask layer (B) using a oxide etch process<sup>l</sup> on a TEL Unity II DRM chamber, followed by poly etch<sup>m</sup> (C) on a Lam 9400PTX chamber and resist stripped<sup>n</sup> using a Fusion ash chamber. The final image (D) was obtained following hardmask strip using wet BOE process<sup>o</sup>. We believe this work represents the first successful pattern transfer feasibility demonstration, into realistic substrate material (poly-Si), using ultra thin resist with 157nm optical lithography. We feel this capability demonstration signifies an important progress in bringing 157nm optical lithography for 100nm-technology node.

<sup>g</sup> Contact TEL for process details

<sup>h</sup> for 2D we determined that n=1.509 and k=0.196 at 157.6nm

<sup>i</sup> PAB=145°C/60S, PEB=145°C/60S, DEV=0.26N TMAH/40S

<sup>j</sup> PAB=145°C/60S, PEB=145°C/60S, DEV=0.26N TMAH/40S

<sup>k</sup> 0.6NA, 0.7 $\sigma$

<sup>l</sup> 50mT, 1500W, C<sub>4</sub>F<sub>8</sub>/Ar/O<sub>2</sub>=7/500/2sccm, 10sec, @ 60°C

<sup>m</sup> Step1: Break Through; 10mT, T/B=100/200W, Cl<sub>2</sub>/HBr=50/50sccm, 10sec, Step2: Main Etch; 20mT, T/B=450/45W, Cl<sub>2</sub>/HBr/He+O<sub>2</sub>=75/200/10sccm, 60sec; all @ 60°C

<sup>n</sup> 1Torr, 1500W, O<sub>2</sub>/N<sub>2</sub>+H<sub>2</sub>/CF<sub>4</sub>=2000/300/5sccm, 60sec @ 270°C

<sup>o</sup> 5sec @ RT in HF/NH<sub>4</sub>F=34/5 buffered solution by Ashland Chemical

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**Table I:** Optical constants of various BARC/hardmask material determined, at lithographically important wavelengths, in this study.

	157.6nm		193nm		248nm		Remark
	n	k	n	k	n	k	
SiN:	PE-CVD Silicon Nitride						
Si Rich	1.917	1.063	2.183	0.909	2.407	0.423	Supplier "A"
Std. (A)	2.156	0.990	2.398	0.638	2.294	0.087	"
Si Poor	2.249	0.935	2.502	0.271	2.162	0.012	"
Std. (N)	2.124	1.060	2.354	0.530	2.348	0.212	Supplier "N"
SiON:	PE-CVD Silicon Oxinitride						
Std.	1.663	0.775	1.826	0.658	2.017	0.487	Supplier "A"
SiO <sub>2</sub> :	TEOS Oxide						
LPTEOS	1.619	0.001	1.522	0.017	1.484	0.001	Furnace Oxide
PETEOS	1.629	0.011	1.555	0.005	1.500	0.001	PE-CVD Oxide
SiCN:	PE-CVD Silicon Carbide						
DOE:+10% (516)	2.069	0.775	2.191	0.308	2.015	0.063	"series" Deposition
DOE:+10% (298)	2.092	0.658	2.074	0.302	1.881	0.074	"
Center (506)	2.055	0.733	2.163	0.283	1.976	0.053	"
Center (275)	2.085	0.676	2.087	0.293	1.885	0.060	"
DOE:-10% (508)	2.040	0.701	2.131	0.267	1.944	0.049	"
DOE:-10% (248)	2.128	0.738	2.163	0.294	1.958	0.040	"
DOE: Center (495)	2.067	0.758	2.219	0.302	2.026	0.062	"single" Deposition
DOE: Center (254)	2.142	0.815	2.209	0.344	2.013	0.057	"
TiN:	PVD Titanium Nitride						
Std., DOE 1	1.416	1.703	1.833	1.781	2.349	1.523	
DOE 2	1.660	1.423	1.816	1.847	1.719	2.378	
DOE 3	1.427	1.674	1.860	1.834	2.417	1.714	
DOE 4	1.684	1.485	1.849	1.867	1.712	2.270	
DOE 5	1.498	1.686	1.894	1.759	2.320	1.542	
LowK:	Low K (dielectric constant) Dielectric Material						
OSG	1.689	0.067	1.541	0.000	1.471	0.005	PE-CVD LowK
SOD	1.417	0.043	1.319	0.001	1.279	0.001	Spin on LowK
Bi-layer:	ARCH Bi-layer Resist System						
Top	1.803	0.218	1.730	0.019	1.569	0.007	"LSM-96-006"
Bottom	1.716	0.172	1.595	0.303	1.669	0.012	"TCU 98.1"

**Table II:** Optical constants of SiN vs. atomic compositions: DOE experiment of gas ratio variation.

Process Condition: Gas Flow, sccm		% Atom by RBS-HFS			Optical Constants by VUV-VASE ( $\lambda$ in nm)					
DOE #	SiH <sub>4</sub> /NH <sub>3</sub>	%Si	%N	%H	n (157.6):	k (157.6):	n (193):	k (193):	n (248):	k (248):
DOE 1	10.0	44.0%	42.5%	13.5%	1.917	1.063	2.183	0.909	2.407	0.423
DOE 2	2.7	39.0%	45.9%	15.1%	2.156	0.990	2.398	0.638	2.294	0.087
DOE 3	1.1	35.0%	48.6%	16.4%	2.249	0.935	2.502	0.271	2.162	0.012
X-tal Si: Lit.[3]		100.0%			0.495	2.041	0.883	2.778	1.573	3.567



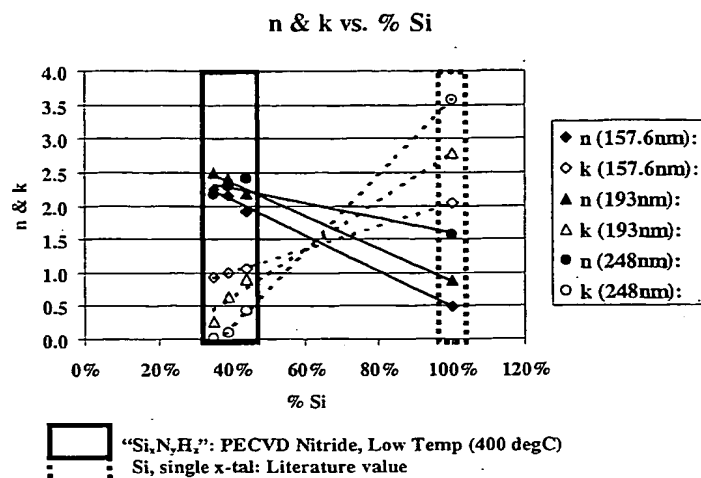


Figure 1: Plot of optical constants vs. %Si of various SiN films.

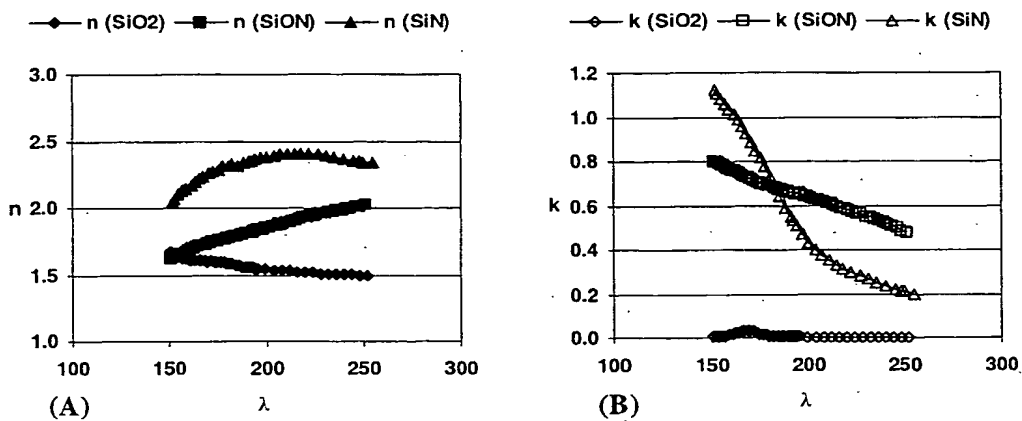


Figure 2: Comparative plot of optical constants of SiO<sub>2</sub>, SiON and SiN.

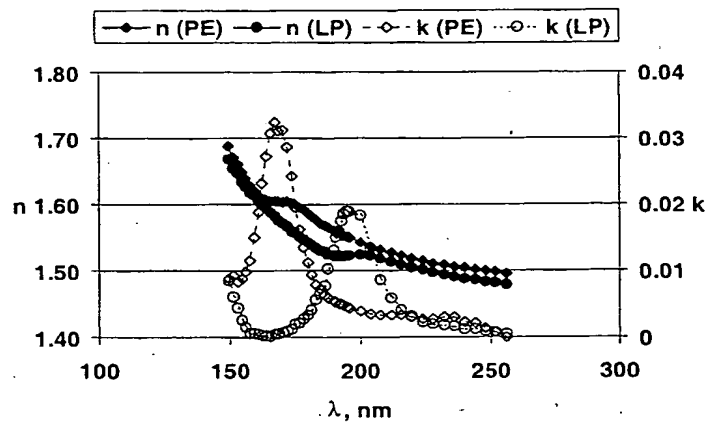
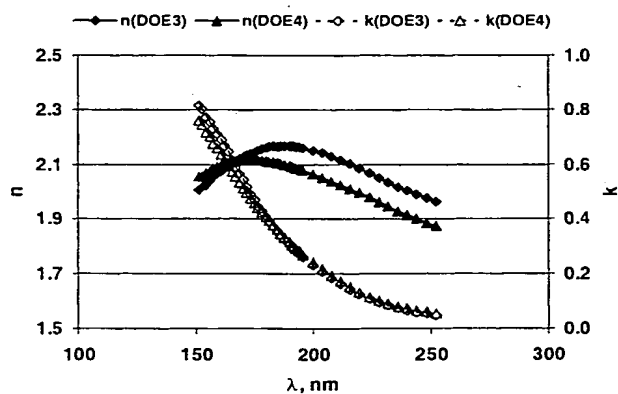


Figure 3 : Plot of optical constants of two types of TEOS oxide studied.

**Table III:** Optical constants of SiCN vs. atomic Compositions: DOE experiment of gas ratio variation.

		% Atom by RBS-HFS					Optical Constants by VUV-VASE ( $\lambda$ in nm)					
DOE #	Thk.	%Si	%C	%N	%O	%H	n (157.6):	k (157.6):	n (193):	k (193):	n (248):	k (248):
DOE 1	516	24%	24%	14%	3%	35%	2.069	0.775	2.191	0.308	2.015	0.063
DOE 2	298	-	-	-	-	-	2.092	0.658	2.074	0.302	1.881	0.074
DOE 3	506	25%	21%	14%	4%	36%	2.055	0.733	2.163	0.283	1.976	0.053
DOE 4	275	-	-	-	-	-	2.085	0.676	2.087	0.293	1.885	0.060
DOE 5	508	22%	24%	13%	3%	38%	2.040	0.701	2.131	0.267	1.944	0.049
DOE 6	248	-	-	-	-	-	2.128	0.738	2.163	0.294	1.958	0.040
DOE 7	495	23%	20%	17%	3%	37%	2.067	0.758	2.219	0.302	2.026	0.062
DOE 8	254	-	-	-	-	-	2.142	0.815	2.209	0.344	2.013	0.057



**Figure 4:** Optical constants determined for ~500Å (DOE3) and ~250Å (DOE4) of SiCN films

**Table IV:** Optical constants of TiN vs. atomic compositions: DOE experiment of gas ratio variation.

		DOE1	DOE2	DOE3	DOE4	DOE5	TiN Film: Lit. [4]
Process Condition: Gas Flow, sccm	N <sub>2</sub>	78	78	39	78	39	
	Ar	0	21	10.5	10.5	21	
% Atom by RBS	[Ti], %Ti	47	47	56	48	56	-
	[N], %N	53	53	44	52	44	-
Optical Constants by VUV-VASE	n (157.6nm):	1.416	1.660	1.427	1.684	1.498	-
	k (157.6nm):	1.703	1.423	1.674	1.485	1.686	-
	n (193nm):	1.833	1.816	1.860	1.849	1.894	1.581
	k (193nm):	1.781	1.847	1.834	1.867	1.759	1.306
	n (248nm):	2.349	1.719	2.417	1.712	2.320	1.878
	k (248nm):	1.523	2.378	1.714	2.270	1.542	1.309

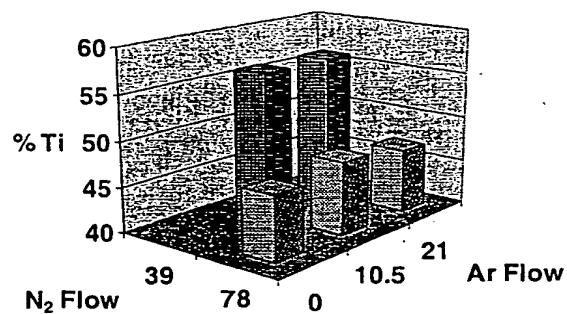


Figure 5: Ti contents dependency on N<sub>2</sub> and Ar flow in PVD-TiN film.

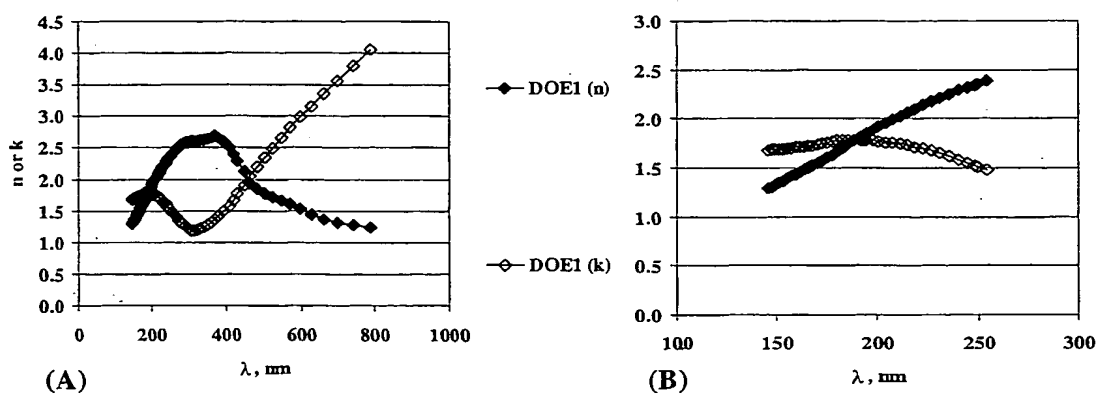


Figure 6: Optical Constants plot of TiN film: Entire range (140nm to 810nm) we've measured and expansion of lithographically important range (140nm to 260nm).

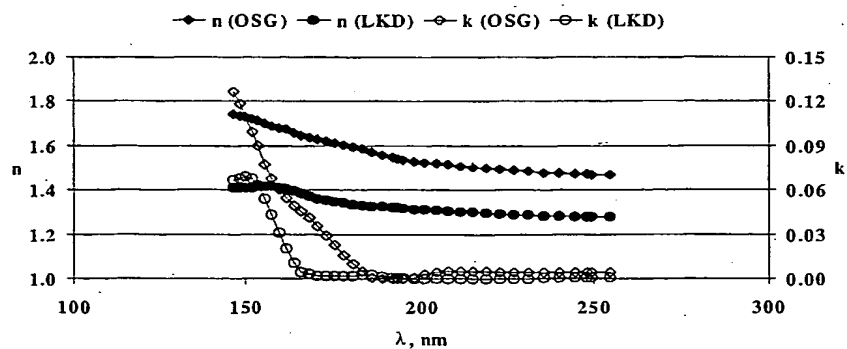
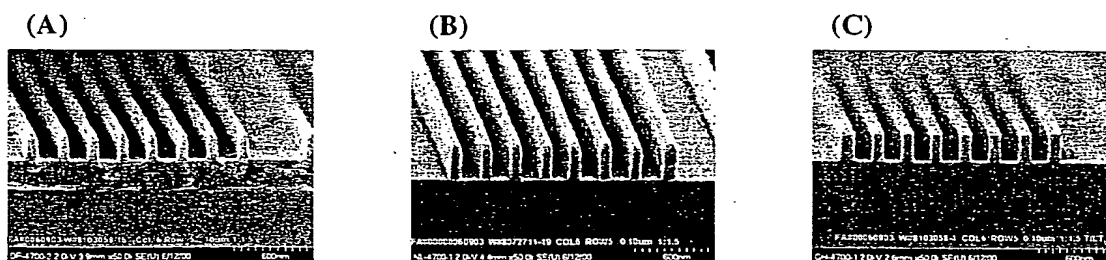
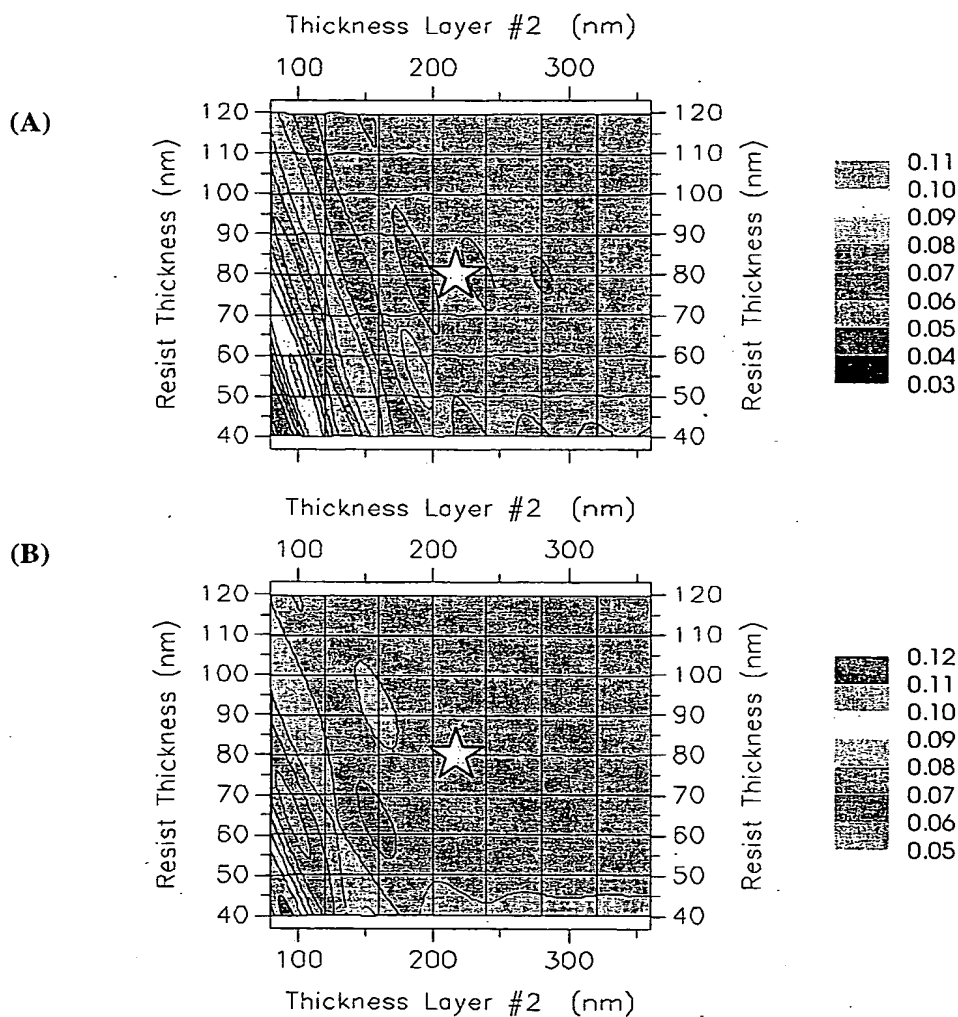


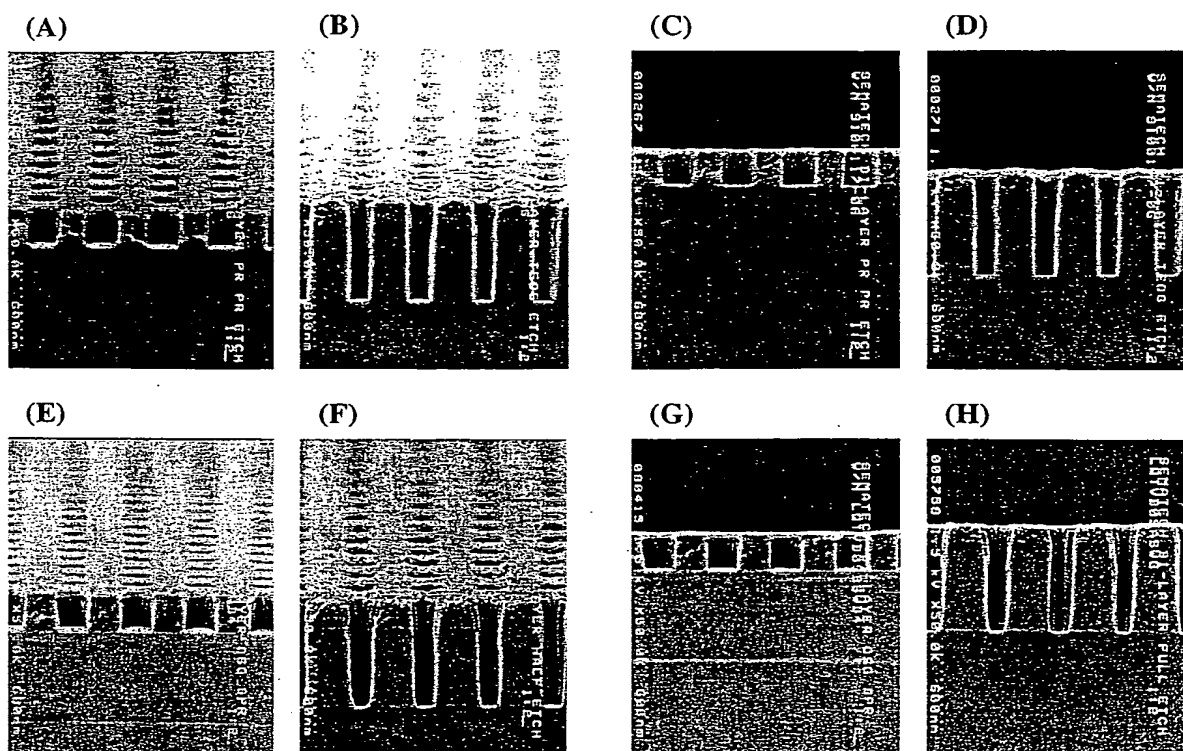
Figure 7: Plot of optical constants of LowK dielectrics studied.



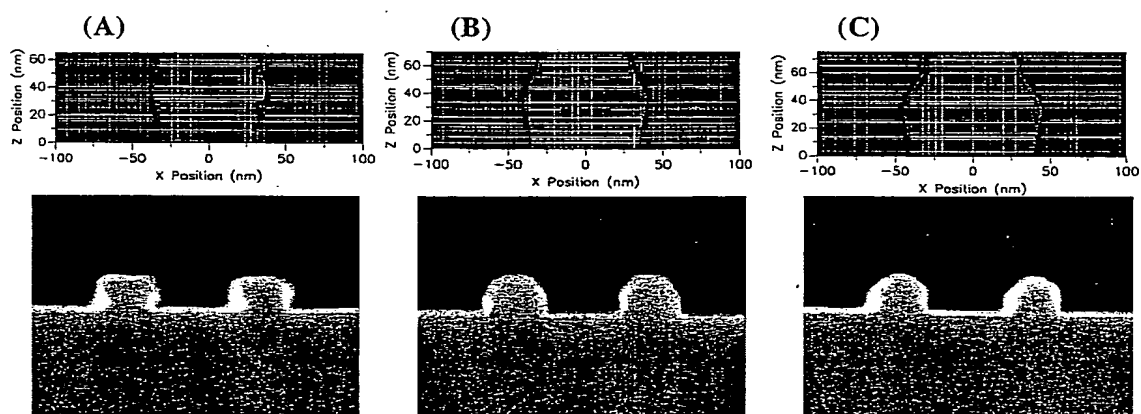
**Figure 8:** SEM micrographs of 193nm pattern generated with ultra thin bi-layer process. A: Bottom layer dry developed following 193nm exposure; B: Pattern on poly/resist following poly etch; C: Pattern on poly upon removal of resist.



**Figure 9:** Bi-layer system (on 600nm of PETEOS) resist reflectivity simulation results at 193nm (A) and 157nm (B) exposure.



**Figure 10:** SEM micrographs of 600nm PETEOS (A-D) and OSG (E-H) pattern generated with ultra thin bi-layer process (using 193nm exposure).



**Figure 11:** Prolith II simulation results (upper) and corresponding SEM micrographs (lower) of 2D resist pattern (on Si substrate) at various resist thickness (A: 65nm, B: 70nm and C: 75nm).

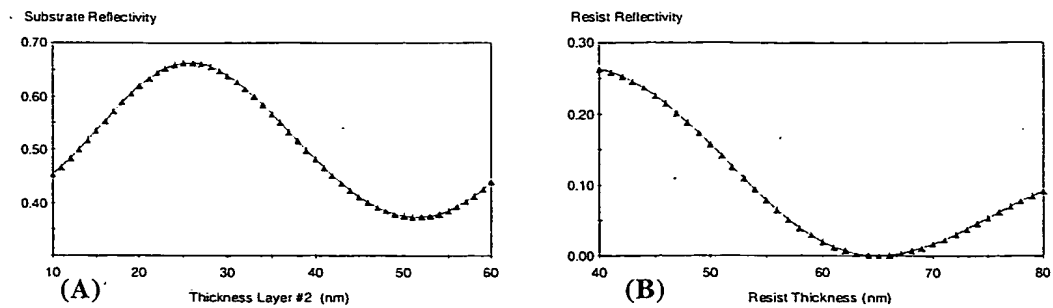


Figure 12: Plots of substrate reflectivity (A) calculated at various hardmask (LPTEOS) thickness and resist reflectivity (B) calculated at LPTEOS thickness of 52nm (substrate reflectivity minimum).

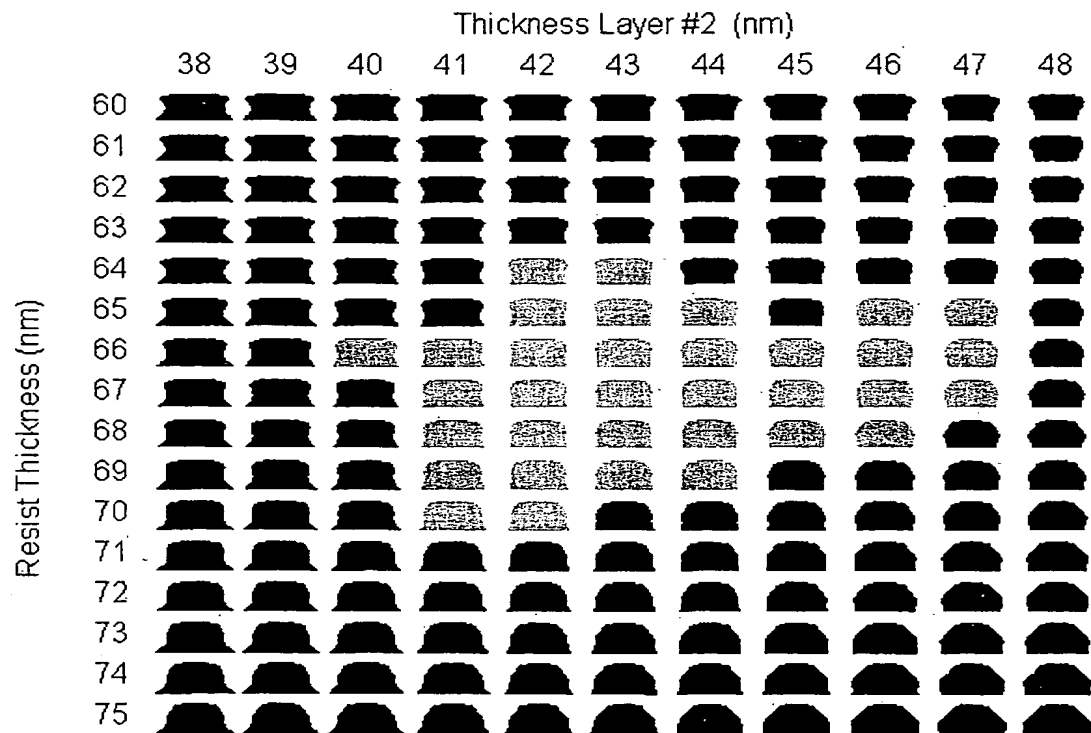
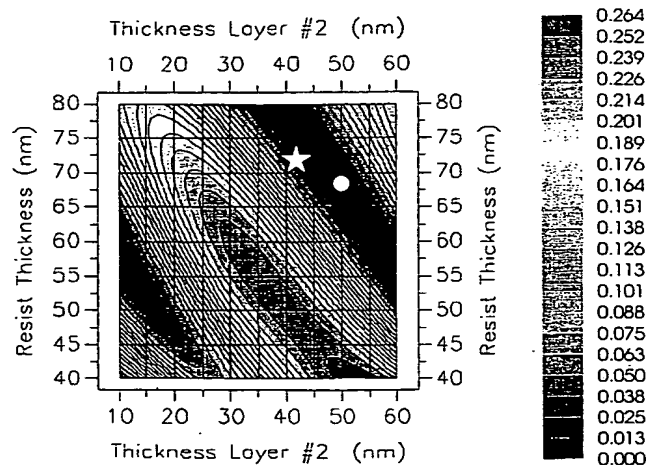
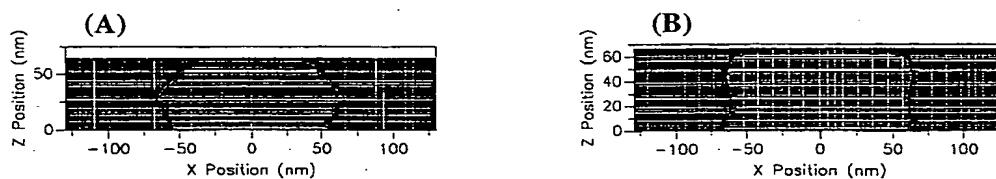


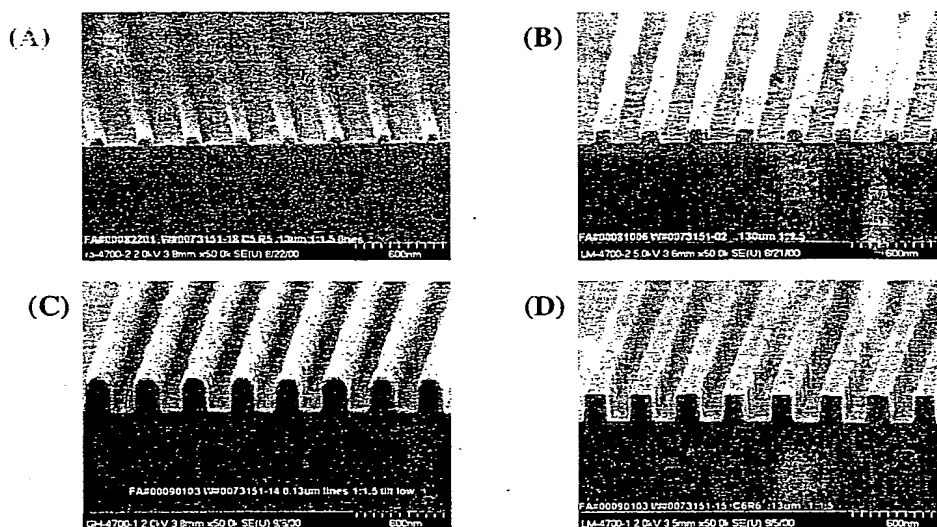
Figure 13: Prolith II simulation results showing resist sidewall profile vs. 2D and LPTEOS thickness. Lighter tone indicates combination with acceptable profiles ( $95^\circ > \text{sidewall angle} > 85^\circ$ ).



**Figure 14:** Contour plot of resist reflectivity vs. resist (2D) and hardmask (LPTEOS) thickness (for patterning on 100nm poly-Si).



**Figure 15:** Resist profile comparison of 2D processes (for 157nm exposure) using film stacks (2D/LPTEOS) of 65/52nm (A) and 67/42nm (B).



**Figure 16:** SEM micrographs of 157nm pattern (130nm 1:1.5) generated with UTR 2D on LPTEOS Oxide film as hardmask. A: Pattern on 2D resist as wet developed following 157nm exposure; B: Pattern on LPTEOS/resist following HM etch; C: Pattern on Poly/LPTEOS/resist following poly etch; D: Pattern on Poly upon removal of resist and LPTEOS.